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A Methodology for Estimating Army Training and Testing Area Carrying Capacity (ATTACC) Vehicle Severity Factors and Local Condition Factors

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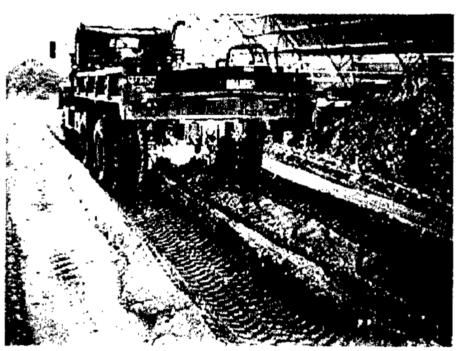

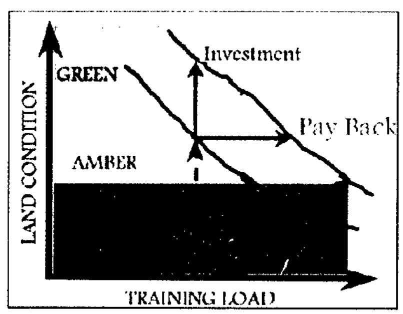

Engineer Research and Development Center

Foreword

This study was conducted for the Strategic Environmental Research and Development Program (SERDP) Office under Work Unit EL9, CS-1102, "Improved Units of Measure for Training and Testing Area Carrying Capacity." The technical monitor was Dr. Robert W. Holst, Compliance and Conservation Program Manager, SERDP. Mr. Bradley P. Smith is the Executive Director, SERDP.

The work was performed jointly by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL) and the Mobility Systems Division (MSD), Geotechnical Laboratory (GL). The CERL Principal Investigator was Mr. Alan B. Anderson. The GL Principal Investigator was Ms. Patricia M. Sullivan. Dr. Niki Deliman; Mses. Stephanie Price and Nora Ponder, MSD; and Ms. Shaundra Simmons, Contract student, provided technical assistance. The technical editor was Gloria J. Wienke, Information Technology Laboratory. Dr. W. Willoughby is Acting Chief, MSD, and Dr. W. F. Marcuson III is Director, GL. Mr. Steve Hodapp is Chief, CEERD-CN-N, and Dr. John T. Bandy is Chief, CEERD-CN. The associated Technical Director is Dr. William D. Severinghaus. The Acting Director of CERL is Dr. Alan W. Moore.

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Background

ITAM Program

The Department of Defense (DoD) is responsible for administering more than 25 million acres of Federally owned land in the United States (Public Land Law Review Commission 1970), making it the fifth largest Federal land managing agency. In addition, DoD military branches have agreements with states and other Federal land-managing agencies to allow use of 15 million acres for training (Council on Environmental Quality 1989).

The Integrated Training Area Management (ITAM) Program is the Army's program for managing training land. A major objective of the ITAM program has been to develop a method for estimating training land carrying capacity. Training land carrying capacity is defined by the Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS) as the amount of training that a given parcel of land can accommodate in a sustainable manner, based on a balance of use, condition, and maintenance practices. The Army Training and Testing Area Carrying Capacity (ATTACC) program is an initiative sponsored by the ODCSOPS to estimate training land carrying capacity.

The ATTACC methodology is used to estimate training and testing land carrying capacity. The methodology is also used to determine land rehabilitation and maintenance costs associated with land-based training and other land uses. The *ATTACC Handbook* (U.S. Army Environmental Center [AEC], Draft 1999), Army Regulation (AR) 350-4, and Department of the Army Pamphlet (DA PAM) 350-4 document the standard operating procedures for implementing ATTACC.

ATTACC Methodology

The Evaluation of Land Value Study (ELVS) methodology, an initiative sponsored by ODCSOPS and the Assistant Secretary of the Army (Installations, Logistics, and Environment) [ASA (IL&E)], was developed to estimate training land carrying capacity and the cost of land rehabilitation and maintenance associated with land-based training (Anderson et al. 1996). The ELVS methodology quanti-

fies training land condition in terms of Maneuver Impact Miles (MIM) based on mileage projections from the Battalion Level Training Model (BLTM) and training event and vehicle impact severity factors (Figure 1). A modification of the Revised Universal Soil Loss Equation (RUSLE) was used to estimate land condition in terms of erosion status as a function of the training load. Land rehabilitation and maintenance costs were obtained from existing installation records and regional cost estimates of particular practices. The ELVS methodology was applied to eight pacing units in heavy maneuver training at Fort Hood, TX, and the Combat Maneuver Training Center, Hohenfels, Germany.

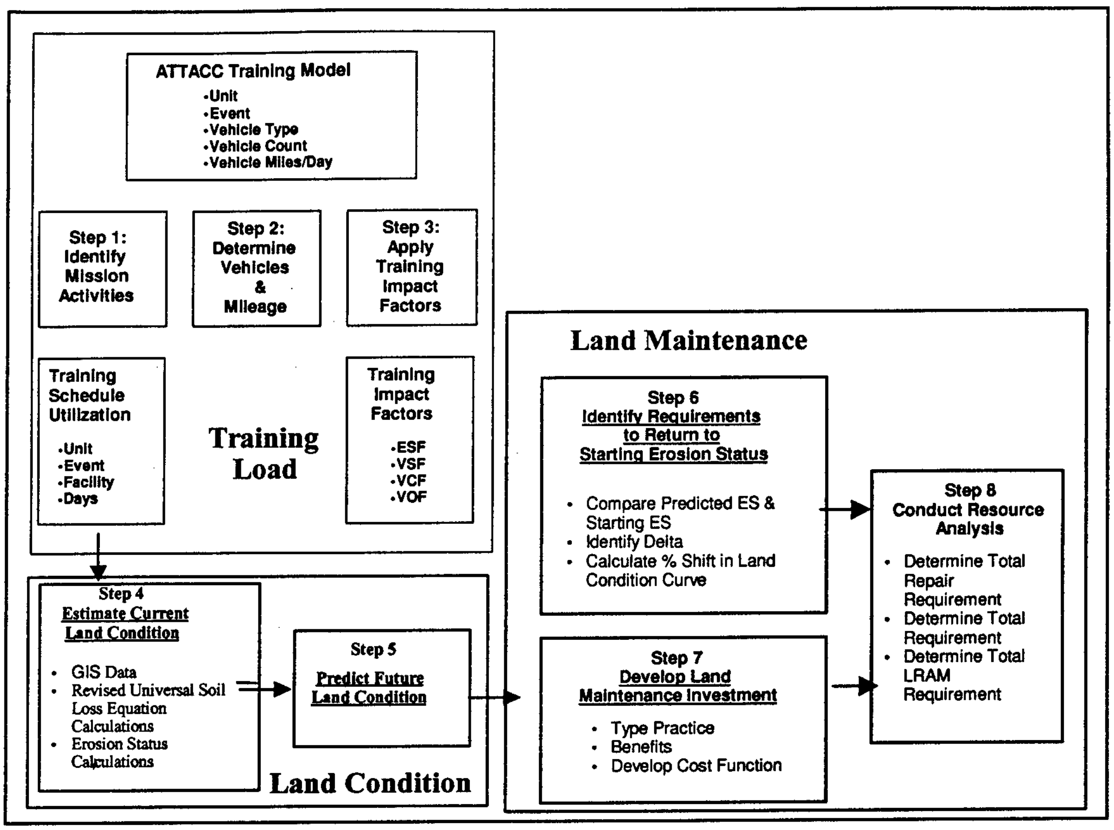

Figure 1. Conceptual diagram of the ATTACC methodology.

The ELVS methodology was expanded, updated, and redesignated as the Army Training and Testing Area Carrying Capacity (ATTACC). The ATTACC methodology extends the ELVS initiative to include all types of Army units (including unique combat units), Army service schools, Reserve Component (RC) units and RC-unique requirements. The ITAM program is integrating the ATTACC methodology into the Army's current Weapon System Cost Factor Development Program and providing tools for installation personnel to use in the development of local requirements and impacts analysis. The ATTACC methodology is being incorporated into the Range Facilities Management and Support System (RFMSS) to provide installation schedulers with a means of estimating training load dur-

ing scheduling activities. The ATTACC methodology has been demonstrated at 13 installations representing diverse ecosystems and missions.

Training load is the term used to describe the collective impact of all military activities that occur on a given parcel of land. ATTACC measures training load in terms of MIM. One MIM has the equivalent impact of an M1A2 tank driving 1 mile in an armor battalion field training exercise (FTX). The MIM value for each mission activity is derived from the number and types of vehicles used, the miles that each vehicle travels, and the type of training event.

The mathematical equation for calculating training load in ATTACC is shown in Equation 1. Training load is calculated using Training Impact Factors (TIF). Training Impact Factors include the Event Severity Factors (ESF), Vehicle Severity Factors (VSF), Vehicle Off-Road Factors (VOF), Local Condition Factors (LCF), and Vehicle Conversion Factors (VCF). The ESF is a multiplier that represents the relative impact of an event, as compared to the standard event (Armor Battalion FTX). The VSF is a multiplier that represents the relative impact of a vehicle, as compared to the standard vehicle (M1A2 tank). The VOF is a multiplier that represents the percentage of vehicle mileage typically driven off improved roads. The VCF is a multiplier that represents the area impacted by a vehicle, as compared to the area impacted by the standard vehicle. The LCF is a multiplier that represents the relative impact of vehicle traffic due to different site conditions including soil moisture.

Training load projections are based on Army training doctrine and databases (Battalion Level Training Model [BLTM], and Combined Arms Training Strategy [CATS]). These sources identify the number, type, and duration of events that various unit types will conduct on an annual basis. This information, when combined with unit stationing information from the Army Stationing and Installation Plan (ASIP), provides an estimate of a projected training load. Alternatively, training load projections can be obtained from the RFMSS software program. These data sources provide the type of event, number and type of vehicles, and mileage projections.

Equation 1. ATTACC training load (MIM) equation.

$$MIM = \sum_{E=1}^{e}\left[\left(\sum_{V=1}^{v}\left(Number_V * Mileage_V * VSF_V * VOF_V * VCF_V\right)\right) * Duration_E * ESF_E * LCF_E\right]$$

where:

MIM	= normalized training load (maneuver impact miles)
E	= event (dimensionless)
e	= number of events (dimensionless)

V	= vehicle type (dimensionless)
v	= number of types of vehicles in event E (dimensionless)
Mileage	= daily mileage for vehicle type V for event type E (miles)
Number	= number of vehicles of type V (dimensionless)
VSF	= vehicle severity factor for vehicle type V (dimensionless)
VOF	= vehicle off-road factor for vehicle type V (dimensionless)
VCF	= vehicle conversion factor for vehicle type V (dimensionless)
LCF	= local condition factor for event E (dimensionless)
Duration	= number of days for event type V (days)
ESF	= event severity factor for event type V (dimensionless)

The ESF, VSF, VOF, and LCF values are currently derived using expert opinion. The VCF values are based on published vehicle tire/track widths. Because Training Impact Factors like VSF and LCF are based on subject matter expert opinion, there is an opportunity to improve the accuracy of the ATTACC methodology through improved Training Impact Factors.

ATTACC-Related Army User Requirements

Documentation of the Army's environmental technology requirements has been an iterative process that began with a series of meetings in 1993 and the Office of the Directorate of Environmental Programs' (ODEP) publication, *U.S. Army Environmental Requirements and Needs*. The Army's environmental technology requirements describe the critical research, development, test, and evaluation (RDT&E) needs for accomplishing the Army's mission with the least impact or threat to the environment. These requirements are Army-level requirements that were reviewed for their impacts to readiness and quality of life, impact or threat to the environment, and timeliness needed for the Army to maintain compliance with environmental regulations. All major commands (MACOMs), major subcommands (MSCs), the Office of the Deputy Chief of Staff for Operations, and the Office of the Deputy Chief of Staff for Logistics (ODCSLOG) were involved in establishing the prioritized and validated list of the Army's environmental technology requirements.

Land Capacity and Characterization is the third priority conservation user requirement. This user requirement defines the Army's need to estimate training land carrying capacity. The user requirement describes the ATTACC methodology as designed to provide scientifically-based information to the land managers to support sound decisionmaking. However, this user requirement defines the current version of ATTACC as limited in its ability to provide the most accurate information for decisionmaking. This limitation is due to the accuracy of input data and a simplistic characterization of the three components of the model. The

user requirement identifies required research and development to improve the accuracy of the ATTACC methodology.

Twenty-eight exit criteria were identified in the *Land Capacity and Characterization* user requirement. Each exit criteria defines a specific product required to address a specific aspect of the overall requirement. Three exit criteria address ATTACC Training Impact Factors. These exit criteria are:

1. Develop a protocol, tool(s), and/or factors for installation-level use that improve the Local Condition Factors (LCF) in the ATTACC methodology.

2. Develop a protocol, tool(s), and/or factors for installation-level use that improve the objectivity of the Vehicle Severity Factors (VSF) in the ATTACC methodology.

3. Develop tool(s) and/or factors for installation-level use that improve the objectivity of the Event Severity Factors (ESF) in the ATTACC methodology.

Besides the Army user requirements, the ATTACC team has used a series of internal and external program audits to evaluate the ATTACC methodology (Concepts Analysis Agency [CAA] 1996). These audits identified a need for a consistent approach to objectively estimate Training Impact Factors. A consistent approach for estimating LCF, VSF, ESF, and VCF is required so that individual impact factors do not consider impacts already considered in other impact factors. The approach should make use of current scientific knowledge rather than relying on subject matter experts.

ATTACC Sensitivity Analysis

A sensitivity analysis is an evaluation of the magnitude of changes in a model's output as a function of changes in the input parameter values. Moreover, a sensitivity analysis of a model's responses to variations in input values can be used to determine the relative importance of individual input values. Results of a sensitivity analysis are used to prioritize data acquisition and model development efforts.

A sensitivity analysis of the ATTACC methodology has been completed (Anderson 1999). The ATTACC methodology is sensitive to changes in training load inputs. All Training Impact Factors have an equal effect on model output due to the form of the training load equation. The importance of Training Impact Fac-

tors to the ATTACC methodology implies that improvements to these factors can result in an overall improvement in model accuracy.

NATO Reference Mobility Model

A collection of computerized models and data used to predict vehicle performance is often referred to as the Family of Mobility Models (FMM). The foundation of FMM is the NATO Reference Mobility Model (NRMM) (Ahlvin and Haley 1992). Derived originally in 1979 from the Army Mobility Model, the NRMM is a collection of equations, algorithms, and data designed to predict operating capability of vehicles operating in a specific terrain. The primary performance prediction of this model is the vehicle's effective maximum speed in a specified terrain. The model considers vehicle factors such as power train, surface traction elements, sizes, and weights, and terrain features including soil properties, topography, vegetation, and weather conditions.

The FMM have been used during the testing and evaluation phases of weapon systems development. The FMM have also been used during wartime operations to evaluate the effect of terrain on weapon systems. The models have been developed so that they are generally applicable worldwide.

While the FMM was developed to predict vehicle performance, the models capture many aspects of vehicle terrain interactions that are important when modeling training-induced disturbance. FMM data and models provide a foundation on which to develop improved ATTACC Training Impact Factors.

Objectives

The first objective of this study is to develop protocols for installation-level use that improve the objectivity of the Vehicle Severity Factors in ATTACC. The second objective of this study is to develop protocols for installation-level use that improve the Local Condition Factor in ATTACC. Both of these objectives are part of the consistent approach for estimating factors individually so impacts are not considered in more than one factor.

Approach

Criteria used in the development of the ATTACC methodology included making it as objective as possible while integrating it with other standard Army programs. The first part of this study was to identify existing Army programs, data,

models, and research that could support developing improved Vehicle Severity Factors and Local Condition Factors. A literature review was completed to identify potential data and research to support development of ATTACC VSF and LCF. The NRMM and associated data were identified as providing a useful foundation on which to base ATTACC VSF and LCF development.

NRMM data and modules were reanalyzed to define which vehicle and site parameters should be included in an ATTACC VSF/LCF model. An evaluation of the effect of soil type, soil moisture, type of vegetation, number of passes, and other relevant factors on estimated VSF was completed. This evaluation was used to determine if one set of VSF would be sufficient for all conditions or if site-specific factors would be required. NRMM data and the model were subsequently modified to develop a methodology for estimating VSF. The methodology was extended to provide estimates of LCF. The methodology was developed to estimate ATTACC VSF and LCF for use in the current ATTACC framework. An approach was also developed to address limitations of the current framework for future implementation. Proposed VSF were compared to the current ATTACC subject matter expert derived VSF. Vehicle Severity Factors were then developed for all ATTACC vehicle types using the proposed methodology.

Scope

The methodology presented in this report for estimating Vehicle Severity Factors and Local Condition Factors is part of a larger effort to provide a consistent approach for estimating ATTACC VSF, VCF, ESF, and LCF. Results of the larger effort will be documented in subsequent reports.

The information provided in this report refers to the ATTACC methodology as described in the *ATTACC Handbook* (AEC 1999).

Mode of Technology Transfer

This methodology will be provided directly to Army personnel responsible for ATTACC implementation. The information is also provided to organizations responsible for developing and refining the ATTACC methodology. Vehicle Severity Factors and Local Condition Factors are available in electronic format for implementation in the existing ATTACC software systems. This report describes the methodology used to develop these factors. The methodology can be used to estimate VSF for new weapon systems as they are developed and fielded.

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

SI conversion factors		
1 in.	=	2.54 cm
1 ft	=	0.305 m
1 lb	=	0.453 kg

2 Proposed ATTACC Vehicle Severity Factors Module

Soil Disturbance

Soil disturbance resulting from military vehicles causes environmental damage by decreasing plant development and increasing erosion (Ayers 1994). Many researchers (Ayers 1994; Shaw and Diersing 1989; Johnson and Smith 1983; Webb and Wilshire 1983; Prose 1985; Braunack 1986a; Braunack 1986b; Ayers et al. 1990; Wilson 1988; Leininger and Payne 1980; Radforth 1973) have investigated the effects of vehicle traffic on soil and environmental damage. Soil puddling, displaced surface horizons, rut formation, increased soil density, decreased macropore space, reduced soil strength and structure, restricted water movement, and physical damage to root systems are potential consequences of vehicle traffic. These soil changes can result in restricted root growth and restricted movement of gasses, water, and nutrients. The physical disturbances affect not only vigor and mortality of vegetation but also site recovery.

The severity of rutting has been correlated with loss of vegetation, exposed soil, increased erosion, soil compaction, and root damage. Sinkage (or soil rutting) is defined as the soil surface surrounding a track or rut that has been displaced, compacted, or has lost strength due to remolding caused by vehicle traffic. Sinkage was selected as the measure of site damage to use in estimating ATTACC VSF.

The environmental and vegetation damage resulting from vehicle traffic is determined by vehicle characteristics and site conditions (Ayers 1994). Vehicle characteristics important in determining site damage include contact area, surface pressure, total weight, track slip, track design, vehicle speed, turning radius, and driving pattern. Site conditions important in determining site damage include soil type, soil moisture, climatic conditions, plant species, and growth stage.

Single-wheel sinkage is a function of vehicle parameters including tire height, width, diameter, deflection, soil strength, wheel load, and slip (Willoughby and Turnage 1990). These relationships were derived from laboratory tests and field

test data. The vehicle's ground clearance is used as the maximum wheel sinkage because a vehicle operating in soft soils is near immobilization or becomes immobilized when its undercarriage drags on the soil surface. Single-wheel sinkage was expanded to include a single track where sinkage is a function of track load, width, length, and soil strength. The sinkage values can be adjusted to account for terrain, slope, and vehicle steering influences.

In the ATTACC methodology vehicle and site conditions are considered in different Training Impact Factors (TIF). Vehicle characteristics including contact area, surface pressure, total weight, track slip, and track design are incorporated into the VSF. Vehicle characteristics including vehicle speed, turning radius, and driving patterns are accounted for in the ESF. Site condition including soil moisture and climatic conditions are accounted for in the LCF. Site condition including soil type, plant species, and growth stages are accounted for in the impact factor of ATTACC. The VCF accounts for vehicle contact area.

While the ATTACC TIF accounted for the important variables affecting vehicle-caused site damage, the use of subject matter experts to estimate factor values does not adequately provide an objective, reproducible methodology that incorporates our current knowledge of vehicle-caused site damage.

Definitions

A number of terms used in the proposed VSF and LCF equations have very specific meanings. Each term used in these equations is defined in the following text in a manner consistent with current engineering standards (Anon 1968). Figures 2 and 3 show the physical measurements of many of the terms.

Sinkage is the soil surface surrounding a track or rut that has been displaced, compacted, or has lost strength due to remolding caused by vehicle traffic.

Rating Cone Index (RCI) is an index of soil shear strength that includes consideration of the sensitivity of soil to strength losses under vehicular traffic. It is defined as the product of cone index and remolding index for the particular layer of soil.

Tire Diameter (d) is the outside diameter, not counting the tread height, of an inflated but unloaded tire.

Tire Width (b) is the distance between the extreme points on the tire carcass area of an inflated but unloaded tire.

Vehicle Weight is the total weight of a vehicle.

Tire Deflection (δ) is the distance between the outer surface of a loaded tire and the outer surface of an inflated but unloaded tire taken at the center of the carcass cross section on a non-yielding surface.

Tire Section Height (h) is the distance from the lip of the rim flange to the outer tire surface, not counting the tread height, of an inflated but unloaded tire.

Track Length is the length of track in contact with the ground.

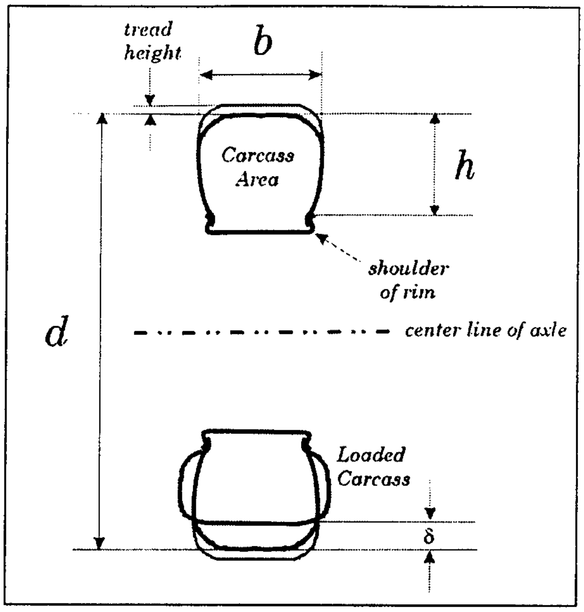

Figure 2. Wheeled vehicle measurement variables.

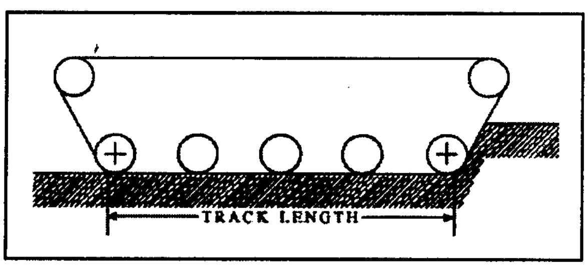

Figure 3. Tracked vehicle measurement variables.

Single-Pass Sinkage Module

A single-pass rut depth module was developed for use. A single-pass module meets the description of impact damage as defined in the ATTACC methodology. Rut depth was used as a measure of damage because it incorporates physical disturbance of the soil, including compaction and deformation. These factors sig-

nificantly affect the plant root damage and regrowth. If ruts are forming in the soil, above-ground vegetation damage is assured in vegetated areas.

Separate equations for estimating sinkage from wheeled and tracked vehicles are required because of the differences in vehicle-site interactions (Murosky and Hasson 1991; Ahlvin and Haley 1992; Willoughby and Turnage 1990; Burger et al. 1985).

Wheeled Vehicles Module

A single-pass sinkage equation for wheeled vehicles is:

Equation 2. Sinkage equation for wheeled vehicles.

$$Sinkage = \frac{5 * TireDia}{\left[\dfrac{RatingConeIndex}{\left[\dfrac{VehWeight / NumWheel}{TireDia * TireWidth} \right] * \left[1 - \left[\dfrac{TireDefl}{TireSectHt} \right] \right]^{3/2} * 0.7247797} \right]^{5/3}}$$

where

Sinkage	= Wheel Sinkage or Rut Depth (in.)
RatingConeIndex	= Rating Cone Index of the soil (unitless)
TireDia	= Tire Diameter (in.)
TireWidth	= Single Tire Width (in.)
VehWeight	= Total Vehicle Weight (lb)
NumWheel	= Total Number of Wheels (unitless)
TireDefl	= Tire Deflection (in.)
TireSectHt	= Tire Section Height (in.)

The wheeled sinkage is the minimum of the calculated sinkage or the vehicle ground clearance.

Tracked Vehicles Module

A single-pass sinkage equation for tracked vehicles is:

Equation 3. Sinkage equation for tracked vehicles.

$$Sinkage = TrLen * 0.00443 * e^{\left[\frac{5.887*\left[\frac{VehWeight / NumTrac}{TrLen*TrWidth}\right]}{RatingConeIndex}\right]}$$

where

Sinkage	= Track Sinkage or Rut Depth (in.)
TrLen	= Length of track in contact with the ground (in.)
RatingConeIndex	= Rating Cone Index of the soil (unitless)
VehWeight	= Total Vehicle Weight (lb)
NumTrac	= Number of tracks (unitless)
TrWidth	= Single Track Width (in.)
RatingConeIndex	= Rating Cone Index of the soil (unitless)

The track sinkage is the minimum of the calculated sinkage or the vehicle ground clearance.

Rating Cone Indices for Representative Soil Moisture

The Rating Cone Index (RCI) is a soil property that indicates the strength of a soil and is a function of the in situ soil type and moisture conditions. Because the methodology would need to be applicable at any site, the concept of a representative moisture condition for typical soil types expected to be encountered at any site was developed. The Soil Moisture Strength Prediction Model Version II (SMSP II) (Sullivan et al. 1997) was used to predict the representative soil moisture conditions and corresponding RCI values for Unified Soil Classification System (USCS) soil types most likely to be encountered at a given area of interest.

The representative soil moisture condition was obtained by taking the average of the field maximum and field minimum moisture content values (which correspond to the upper and lower limits in the range of naturally occurring moisture content) for each soil type for typical site characteristics. Table 1 lists and defines USCS soil types (U.S. Army Waterways Experiment Station [USAWES] 1960). Table 2 gives the equations used to predict RCI values as a function of moisture content. Table 3 gives the representative soil moisture contents and corresponding RCI values predicted for each USCS soil type.

Table 1. USCS soil names and descriptions.

Soil Type Code	Description
SW	This group comprises well-graded gravelly and sandy soils having little or no non-plastic fines.
SP	This group comprises poorly-graded gravels and sands containing little or no non-plastic fines.
SM	This group comprises gravels or sands with fines having low or no plasticity.
SC	This group comprises sandy soils with fines that have either low or high plasticity. The gradation of the materials is not considered significant and both well- and poorly-graded materials are included.
SM-SC	A borderline soil that exhibits characteristics of both SM and SC soil groups. The SM soil group comprises silty sands while the SC group comprises clayey sands.
CL	Primarily inorganic clays with low liquid limit (i.e., less than 50).
ML	This group comprises predominantly silty materials and micaceous or diatomaceous soils with low liquid limits.
CLML	This group comprises a borderline soil that exhibits characteristics of both CL and ML soil groups. The CL soil comprises low plasticity clays and the ML soil group comprises silts with low plasticity.
CH	This group comprises predominantly primarily inorganic clays with high liquid limit (i.e., greater than 50).
MH	This group comprises predominantly silty materials and micaceous or diatomaceous soils with high liquid limits.
GC	This group comprises gravelly soils with fines that have either low or high plasticity. The gradation of the materials is not considered significant and both well- and poorly-graded materials are included.
Pt	This group is comprised of highly organic soils that are very compressible, frequently have fibrous vegetable matter.
OL	This group is characterized by the presence of organic matter. Organic silts and clays are classified in this group if they have materials with low plasticity.
OH	This group is characterized by the presence of organic matter. Organic silts and clays are classified in this group if they have materials with high plasticity.

Table 2. Equations for estimating rating cone index values for specific soil moisture values.

Soil Type	Equation
SW, SP	RCI = exp [3.987 + 0.815 ln (% Moisture Content)]
SM, SC, SM-SC	RCI = exp [12.542 – 2.955 ln (% Moisture Content)]
CL	RCI = exp [15.506 – 3.530 ln (% Moisture Content)]
ML	RCI = exp [11.936 – 2.407 ln (% Moisture Content)]
CL-ML	RCI = exp [14.236 – 3.137 ln (% Moisture Content)]
CH	RCI = exp [13.686 – 2.705 ln (% Moisture Content)]
MH	RCI = exp [23.641 – 5.191 ln (% Moisture Content)]
OL	RCI = exp [17.399 – 3.584 ln (% Moisture Content)]
OH	RCI = exp [12.189 – 1.942 ln (% Moisture Content)]

Table 3. Representative soil moisture values and predicted rating cone index values for USCS soil types.

Soil Type	% Moisture Content	Rating Cone Index
SW	12.11	411.46
SP	12.60	424.82
SM	10.07	304.07
SC	14.24	109.33
SM-SC	12.94	145.02
CL	15.07	243.83
ML	17.04	139.98
CLML	18.28	167.36
CH	26.96	118.48
MH	36.97	134.45
OL	30.48	172.81
OH	58.65	72.38

Single-Pass Sinkage Module Data Sources

Data required to implement the equations listed in the previous sections are readily available. Vehicle characteristics are available from different DoD databases and are available in published sources (Jane's 1999). Site information such as soil type is available from the National Imagery and Mapping Agency's (NIMA) Interim Terrain Data (ITD) and ITAM geographic information system (GIS) databases. Soil type data are also available from Natural Resources Conservation Service (NRCS) published soil surveys. Attribute values for these soil surveys are available from the Map Unit Interpretation (MUIR) database. Representative soil moisture values can be calculated from existing data (Sullivan et al. 1997).

Vehicle Severity Factors Calculation

The ATTACC standard is the M1A2 Abrams Tank in an armored battalion in a field training exercise. Training impact factors represent the difference in impact between vehicles and events as compared to the standard. To determine vehicle severity factors, a ratio was taken of the predicted single-pass sinkage values for all vehicles with respect to the M1A2 Tank for identical site conditions (Equation 4). Representative conditions were established as the average of the field maximum and field minimum moisture content values for a specified soil type. Any soil type that occurs on an installation or management area can be used.

Equation 4. Vehicle Severity Factors equation.

$$VSF_v = \frac{Sinkage_v}{Sinkage_{Reference}}$$

where

VSF_v	is the vehicle severity factor for vehicle v.
$Sinkage_v$	is the single-pass rut depth for vehicle v using the same soil type and soil moisture as the reference vehicle.
$Sinkage_{Reference}$	is the single-pass rut depth for the reference vehicle using a reference soil type and soil moisture.

Local Condition Factor Calculation

The ATTACC standard for the LCF is a value of 1 for typical conditions. This usually represents a relatively dry soil that is trafficable. To determine local

condition factors, a ratio was taken of predicted single-pass sinkage values for a vehicle at specified soil moisture to the sinkage for a typical condition (Equation 5). The typical soil moisture value is the value used to estimate VSF. The typical value is not important so long as it is the same as the VSF soil moisture value. This ensures that the VSF and LCF are accounting for different aspects of vehicle damage.

Equation 5. Local Condition Factors equation.

$$LCF_m = \frac{Sinkage_m}{Sinkage_{Reference}}$$

where

LCF_m	is the local condition factor for soil moisture value *m*.
$Sinkage_m$	is the rut depth for soil moisture value *m* for the same type of soil and vehicle used in $Sinkage_{Reference.}$
$Sinkage_{Reference}$	is the rut depth for the reference soil moisture value, soil type, and vehicle type used to calculate VSF.

3 Validation of Proposed ATTACC Vehicle Severity Factors Module

To validate the proposed ATTACC VSF/LCF module, predictions from the proposed module were compared to predictions from the full set of models in the FMM. This approach was selected because the FMM is a model that has been verified with laboratory and field data and represents the most accurate predictions possible without constraints. Studies are underway to validate the proposed module with additional field data.

To validate the proposed VSF methodology, Fort Hood, TX, was chosen as an evaluation site. Fort Hood was selected for several reasons: (a) data were readily available; (b) Fort Hood natural resources personnel expressed interest in the study; (c) Fort Hood is a demonstration site for the Army's Land Management System (LMS); and (d) Fort Hood was one of the original demonstration sites for the ATTACC methodology.

Fort Hood, TX, Study Site

Fort Hood occupies an 87,890-hectare (ha) area (U.S. Department of the Army 1987) in central Texas in Bell and Coryell Counties. The installation Master Plan Report (Nakata Planning Group 1987), which contains detailed information on the Fort Hood environment, is summarized in the following paragraphs.

Fort Hood's climate is characterized by long, hot summers and short, mild winters. Average temperatures range from a low of about 8 °C in January to a high of 29 °C in July. Average annual precipitation is 81 cm. Table 4 shows average monthly and maximum rainfall values for Fort Hood.

Elevation at Fort Hood ranges from 180 to 375 m above sea level with 90 percent below 260 m. Most slopes are in the 2 to 5 percent range with slopes in excess of 45 percent occurring as bluffs along the flood plain and as the sides of slopes on the hills. Soil cover is generally shallow to moderately deep and clayey, underlain by limestone bedrock. Table 5 provides engineering soil types and their abundance at Fort Hood.

Table 4. Average annual climatic data for Fort Hood, TX.

Month	Avg. Monthly Rainfall (in.)	Max. 24-Hour Rainfall (in.)
January	2.0	2.3
February	2.2	2.5
March	2.2	2.0
April	3.7	1.7
May	4.5	8.9
June	3.3	3.4
July	1.8	1.6
August	2.8	2.4
September	3.5	4.8
October	3.8	3.1
November	2.0	2.6
December	1.7	1.5

Table 5. Soil types and descriptions of soils found at Fort Hood, TX.

Soil Type	Description	Percent of Area
CL	Primarily inorganic clays with low liquid limit (i.e., less than 50).	43.8
CH	Primarily inorganic clays with high liquid limit (i.e., greater than 50).	26.4
SC	Sandy soils with fines that have either low or high plasticity. The gradation of the materials is not considered significant and both well- and poorly-graded materials are included.	24.5
CL-ML	A borderline soil that exhibits characteristics of both CL and ML soil groups. The CL soil comprises low plasticity clays and the ML soil group comprises silts with low plasticity.	4.5
SM-SC	A borderline soil that exhibits characteristics of both SM and SC soil groups. The SM soil group comprises silty sands while the SC group comprises clayey sands.	0.5
GC	Gravelly soils with fines that have either low or high plasticity. The gradation of the materials is not considered significant and both well- and poorly-graded materials are included.	0.4

Fort Hood lies in the Cross Timbers and Prairies vegetation area (Gould 1975). The area is normally composed of oak woodlands with grass undergrowth. Traditionally, the predominant woody vegetation consists of ashe juniper (*Juniperus ashei*), live oak (*Quercus fusiformis*), and Texas oak (*Quercus texana*). Under climax conditions, the predominant grasses consist of little bluestem (*Schizachyrium scoparium*) and indian grass (*Sorghastrum nutans*).

The primary mission of Fort Hood is the training, housing, and support of the III Corps and its two divisions (1st Calvary Division and 2nd Armored Division). Support is also provided to other assigned and tenant organizations, as well as the U.S. Army Reserve, the National Guard, the Reserve Officer Training Corps, and the reservists from other services.

Of the 22,700 ha live-fire and impact areas, 8,700 ha are multi-purpose maneuver live-fire areas. The range areas serve as familiarization and qualification firing ranges for all individual weapons, crew-served weapons, and the major weapons systems of active units assigned or attached to the III Corps and Fort Hood. Maneuver areas comprise 52,400 ha (not including the multi-purpose live-fire area). Maneuver areas are used for armored and mechanized infantry forces in the conduct of task force and battalion-level operations, and for company and platoon-level dismounted training, along with engineer, amphibious, combat support, and combat services support training.

Validation Study Design

For a particular area of interest, field-measured moisture content and corresponding RCI readings for the time of year in question can be used directly in the single-pass sinkage equations to most accurately predict VSF/LCF for a specific set of conditions. However, the intent of this validation is not to predict rutting for a specific site condition, but to evaluate how well the proposed module adapted specifically for the ATTACC framework captures the dynamics of a range of typical conditions. We chose to use historical climatic records for the area to derive typical soil moisture contents and RCI values. These values were then used to estimate ATTACC VSF/LCF.

Eight vehicles were selected for evaluation (Table 6): four tracked and four wheeled. Vehicles were selected to represent a range of vehicle types from the ATTACC vehicle database. Tables 7 and 8 provide vehicle parameters required by the sinkage models.

Table 6. Vehicle used to evaluate ATTACC VSF module.

Vehicle Code	Vehicle Description	Vehicle Type	Gross Vehicle Weight (lb)
M1A2 Abrams Tank	M1A2 Abrams Tank	Tracked	140,000
M2A2 Bradley	M2A2 Bradley	Tracked	66,000
M113A3 APC	M113A3 Armored Personnel Carrier	Tracked	27,180
M973 SUSV	M973 Small Unit Support Vehicle	Tracked	10,580
M1075 PLS	M1075 Palletized Load System	Wheeled	81,660
M977 HEMTT	M977 HEMTT	Wheeled	60,375
M923A2	M923A2	Wheeled	32,200
M998 HMMWV	M998 High Mobility Multi-Purpose Wheeled Vehicle	Wheeled	7,500

Table 7. Wheeled vehicle input parameters for selected vehicles.

Vehicle	Tire Diameter (in.)	Weight Per Wheel (lb)	Tire Width (in.)	Deflection (in.)	Section Height (in.)	Ground Clearance (in.)
M1075 PLS	52.9	8166.0	17.2	3.6	13.2	16.5
M977 HEMTT	52.6	7547.0	16.0	3.2	13.8	13.0
M923A2	49.2	5367.0	14.8	2.8	11.7	13.7
M998 HMMWV	37.0	1875.0	12.3	1.9	9.2	11.3

Table 8. Tracked vehicle input paramaters for selected vehicles.

Vehicle	Weight per Track (lb)	Track Width (in.)	Track Length (in.)	Ground Clearance (in.)
M1A2 Abrams Tank	70000.0	25.0	183.1	17.0
M2A2 Bradley	33000.0	21.0	157.0	17.5
M113A3 APC	13590.0	15.0	112.0	16.0
M973 SUSV	5290.0	24.0	78.0	14.0

First, an analysis of the full FMM was conducted to determine the range of sinkage values that could be expected for the range of conditions likely to occur at Fort Hood. An analysis of variance of these data identified the proportion of variation in values that could be accounted for by specific vehicle and site variables. The proposed model could then be evaluated to determine if it is incorporating the correct variables.

The VSF/LCF were then estimated for a range of site conditions to evaluate the effect of selecting a representative site condition. Soil moisture and soil types were evaluated because these were the primary sources of variation in the analysis of variation.

The VSF derived from sinkage equations were then compared to subject matter expert values for the same vehicles to determine whether or not the proposed values agreed with the subject matter experts (i.e., to determine if the factors were missing impacts that the experts considered important) and to assess the impact of the new values on the overall ATTACC program. Finally, proposed VSF were contrasted with predicted sinkage values using site specific data to determine the worst case performance of the factors.

NIMA ITD were used to provide digital terrain data for the study area. The ITD consists of six thematic feature files, including surface materials (soils), surface configuration (slope), surface drainage, vegetation, transportation, and obstacles. A terrain elevation file, consisting of NIMA-produced Digital Terrain Elevation Data (DTED) Level 1 was also used. The two surface conditions considered were dry normal and wet slippery. The dry normal surface condition describes the

driest 30-day soil moisture condition for an average rainfall year and is typically the best surface condition for mobility and limited potential for site damage. The wet slippery surface condition describes the wettest 30-day soil moisture condition for an average rainfall year and represents the worst conditions for mobility and maximum potential for site damage. Soil types considered are those listed in Table 5. Vegetation types considered included: coniferous, deciduous, and mixed forests; coniferous and deciduous vegetation; mixed scrub; and short and tall grasses.

Validation Study Results

Table 9 shows the results of the analysis of variance of the FMM sinkage predictions for Fort Hood. The analysis includes 2 intensities of disturbance, 2 soil moisture levels, 8 vehicle types, 6 soil types, 13 vegetation types, and a range of topography. The primary sources of variation in order of importance are soil moisture level (M), vehicle type (V), number of passes (P), and soil type (S). The main source of variation due to interaction of main effects was moisture by vehicle interaction (M*V).

Table 9. ANOVA of NRMM-based sinkage predictions.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square
PASSES (P)	3521.78	2	1760.89
MOISTURE (M)	7986.76	1	7986.76
VEHICLE (V)	5835.86	7	833.69
SOIL (S)	3089.29	5	617.86
P*M	1085.5	2	542.75
P*V	339.03	14	24.22
P*S	292.55	10	29.25
M*V	2073.65	7	296.24
M*S	3059.1	5	611.82
V*S	823.26	35	23.52
P*M*V	196.03	14	14
P*M*S	285.52	10	28.55
P*V*S	234.34	70	3.35
M*V*S	815.46	35	23.3
P*M*V*S	235.34	70	3.36
Error	255.41	2592	0.1
(Model)	49537.89	287	172.61
(Total)	49793.3	2879	17.3

Tables 10 and 11 provide single-pass sinkage values and corresponding VSF, respectively, for the soil types encountered in the Fort Hood study area. As previously mentioned, all training events are normalized to a standard unit (M1A2). Figure 4 graphically shows VSF for the different soil types. The ranking of the VSF within vehicle type (tracked and wheeled) remained constant but the ranking between vehicle types varied by soil type. Correlation coefficients for VSF calculated for different soil types ranged from a high of over 0.99 to a low of about 0.30. Figures 5 and 6 provide single-pass sinkage values and corresponding VSF, respectively, for a range of soil moisture values. It is evident from these results that VSF varies with site conditions. As sites become wetter, the rate of increase of potential damage due to wheeled vehicles is greater than that of tracked vehicles.

Table 10. Predicted single-pass sinkage values for selected vehicles for diverse soil types.

Soils	Sinkage (in.)							
	M1A2	**M2A2**	**M113A3**	**M973**	**M1075**	**M977**	**M923A2**	**HMMWV**
SW	1.010	0.803	0.557	0.360	0.119	0.135	0.089	0.028
SP	1.003	0.799	0.555	0.359	0.113	0.128	0.084	0.027
SM	1.091	0.844	0.580	0.365	0.197	0.224	0.147	0.047
SC	1.850	1.193	0.767	0.402	1.084	1.234	0.812	0.257
SM-SC	1.510	1.044	0.689	0.388	0.676	0.770	0.507	0.161
CL	1.173	0.886	0.603	0.370	0.284	0.323	0.213	0.068
ML	1.543	1.059	0.697	0.389	0.716	0.815	0.537	0.170
CLML	1.389	0.989	0.659	0.382	0.532	0.605	0.399	0.126
CH	1.734	1.144	0.742	0.398	0.946	1.077	0.709	0.225
MH	1.585	1.078	0.707	0.391	0.767	0.873	0.575	0.182
OL	1.366	0.978	0.654	0.380	0.504	0.574	0.378	0.120
OH	2.813	1.570	0.958	0.435	2.151	2.449	1.612	0.511
GC*	1.095	0.846	0.582	0.365	0.201	0.229	0.151	0.048

* Note that for the GC soil type, the RCI is assumed to be 300 because it is gravel and this value was used directly in the single-pass sinkage equations to derive the sinkage values.

Table 11. Predicted VSF values for selected vehicles for different soil types.

Soil	M1A2	M2A2	M113A3	M973	M1075	M977	M923A2	HMMWV
SW	1.000	0.795	0.552	0.356	0.118	0.134	0.088	0.028
SP	1.000	0.797	0.554	0.358	0.112	0.128	0.084	0.027
SM	1.000	0.774	0.532	0.335	0.180	0.205	0.135	0.043
SC	1.000	0.645	0.415	0.218	0.586	0.667	0.439	0.139
SM-SC	1.000	0.692	0.457	0.257	0.448	0.510	0.336	0.106
CL	1.000	0.755	0.514	0.315	0.242	0.276	0.182	0.058
ML	1.000	0.687	0.452	0.252	0.464	0.528	0.348	0.110
CLML	1.000	0.712	0.475	0.275	0.383	0.436	0.287	0.091
CH	1.000	0.659	0.428	0.229	0.546	0.621	0.409	0.130
MH	1.000	0.680	0.446	0.247	0.484	0.551	0.363	0.115
OL	1.000	0.716	0.479	0.279	0.369	0.420	0.277	0.088
OH	1.000	0.558	0.340	0.155	0.765	0.870	0.573	0.182
GC	1.000	0.773	0.531	0.334	0.184	0.209	0.138	0.044

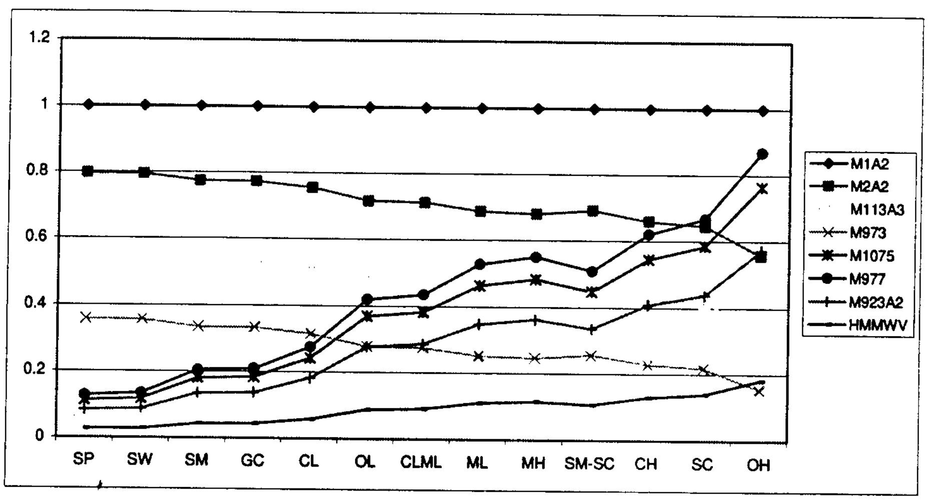

Figure 4. Comparison of relative site damage predictions for selected vehicles and diverse soil types.

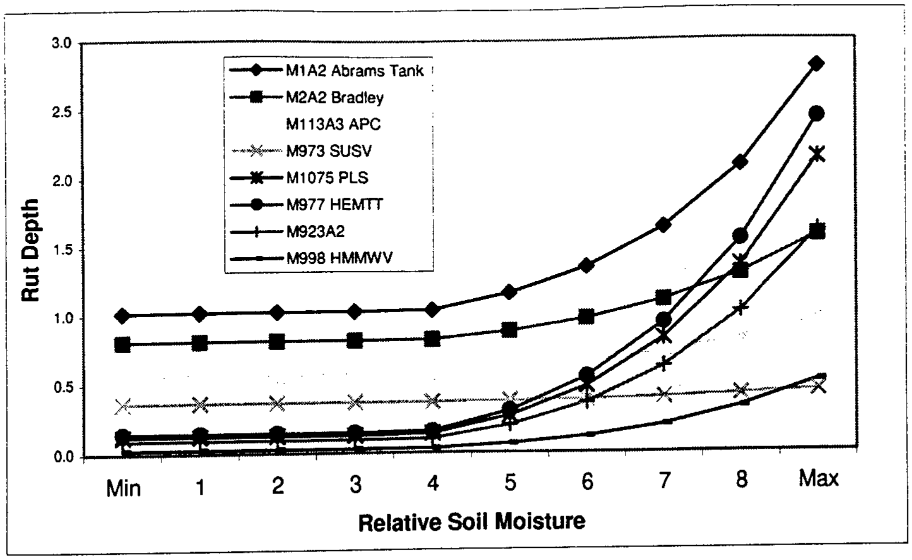

Figure 5. Sinkage estimates for selected vehicles for a CL soil with a range of soil moisture values.

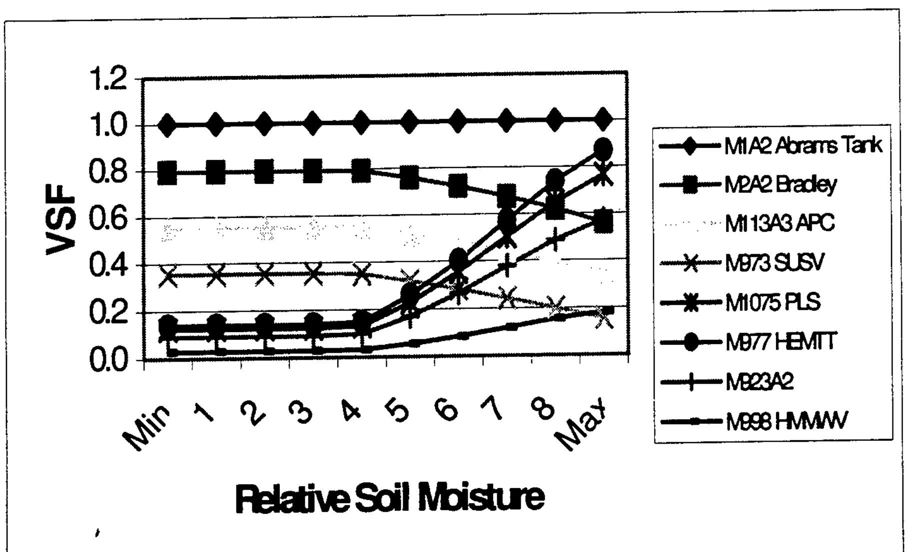

Figure 6. VSF estimates for selected vehicles for a CL soil with a range of soil moisture values.

If vehicle severity factors for wheeled vehicles use a wheeled vehicle as a standard vehicle and tracked vehicles use a tracked vehicle for a standard vehicle, then calculated VSF are relatively constant over a wide range of soil moisture and soil types (Figure 7). This allows the concept of VSF to be used across a wide range of site conditions but requires keeping track of both wheeled and tracked mileage projections. The form of the sinkage equations explains why tracked and wheeled vehicles behave differently for different soil types and a range of moisture values. In the wheeled vehicle equation, a ratio of one sinkage equation to another results in the RCI being dropped from the equation. This means that soil properties and soil moisture do not affect the ratio between two

sinkage estimates for wheeled vehicles. In the tracked vehicle equation, a ratio of one sinkage equation to another does not result in the RCI being dropped from the equation. This means that soil properties and soil moisture do affect the ratio between two tracked vehicles. The difference between the form of the tracked and wheeled vehicle equations explains the interaction between site conditions and vehicle type.

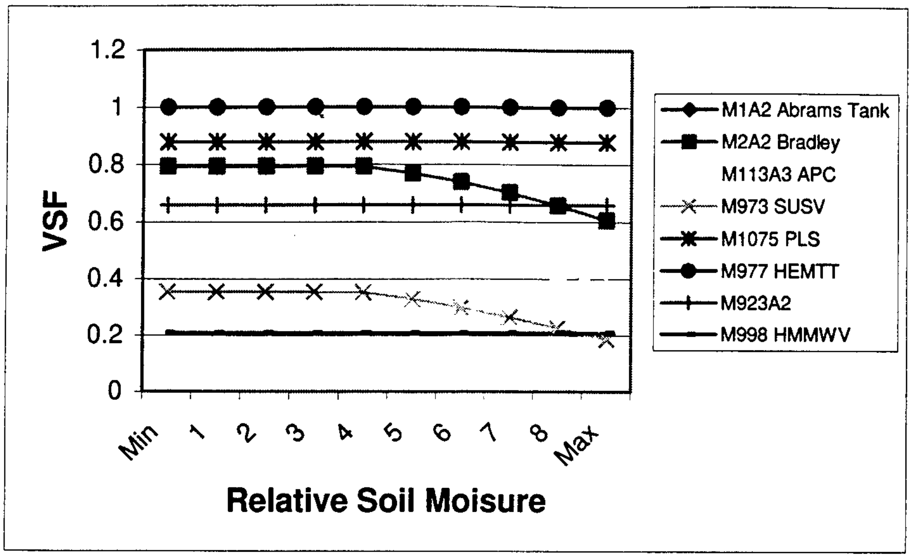

Figure 7. VSF estimates for selected vehicles for a CL soil for a range of soil moisture values when wheeled and tracked vehicles use different standard vehicles for reference.

Correlation of the ATTACC subject matter experts' (SME) VSF with the calculated VSF for various soils ranged from 0.94 to 0.48 (Table 12). It is interesting to note that SME VSF matched the VSF for the soil type that was most dominant at the location with which each SME had the most experience.

Table 12. Correlation coefficients for ATTACC VSF and VSF calculated using sinkage equations for selected soil types.

Soil Type	Correlation Coefficient
CL	0.944
GC	0.936
SM	0.936
OL	0.929
CLML	0.924
SW	0.922
SP	0.920
SM-SC	0.888
ML	0.876
MH	0.860
CH	0.798
SC	0.749
OH	0.481

Figure 8 shows VSF calculated using the proposed methodology, VSF using all available information to calculate rutting depths, and ATTACC SME VSF. The detailed rutting calculations (full model) included soil type, soil moisture, vehicle speed, vehicle characteristics, vegetation, slope, and interactions between these variables. The reduced model VSF are calculated in Chapter 2 of this report. Correlation coefficients between the two sinkage models exceeded 0.99. This means that the reduced model accounted for approximately 99 percent of the variation in the full model.

Figure 8 shows the relationship between VSF calculated from sinkage equations and the SME VSF. The relationship between the factors has a correlation coefficient of 0.90. The rank of the vehicles is the same for both methods but the range of values differs. However, over 85 percent of the variation in SME values can be explained by the sinkage VSF values. This is very good considering the diverse approaches taken to derive the values. The differences in the two VSF estimates was not unexpected; the differences are similar in trend to differences found between SME P factor values and published P factor values in a related unpublished study.

Uncertainty in expert opinions has been extensively studied (Cleaves 1994). Sources of error when SME are used include anchoring, ranking, and scaling. Anchoring is the establishment of a starting value against which other values are compared and is a common source of error with SME. However, this is not an issue with ATTACC SME since the starting point in both methods is predefined. Ranking errors are errors associated with identifying the proper ordering of items. SME are generally good at ranking items. The SME values are ranked the same as the sinkage model rankings. Scaling errors are errors of assigning an exact value to an object. Humans are generally less able to accurately provide scale values than they are to provide accurate ranking values. A tendency of SME is to make only small adjustments from the anchor (starting) value. This may explain why the SME values cover a more narrow range of values than the sinkage model values.

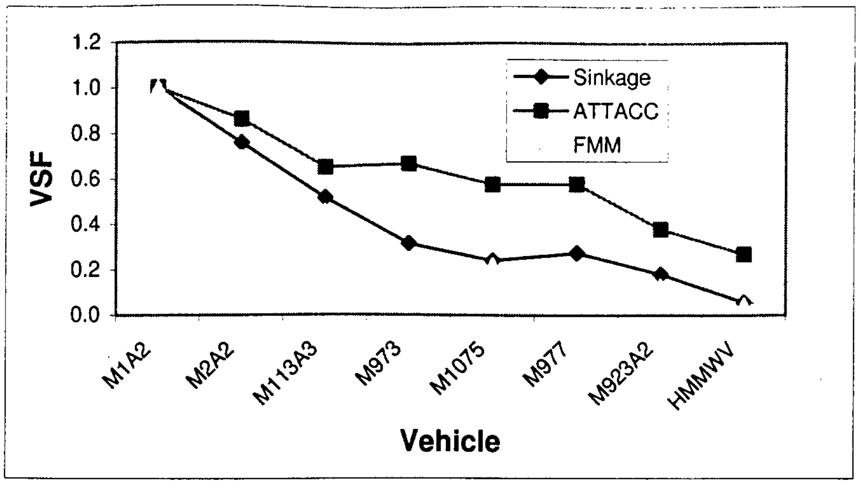

Figure 8. Comparison of calculated VSF with SME VSF.

Figure 9 shows LCF calculated using Equation 4 for each vehicle type. The wheeled vehicles all have the same LCF for a specified soil moisture. Tracked vehicles have approximately the same LCF. The form of the sinkage equations explains these results. In the wheeled vehicle equation, a ratio of one sinkage equation to another that varies only by RCI will result in all model components dropping out of the equation except the RCI values. Thus all wheeled vehicles have the same LCF. In the tracked vehicle equation, a ratio of one sinkage equation to another does not result in all the vehicle properties dropping out of the equation. This means that soil properties and soil moisture both affect the LCF estimates. However, the differences in LCF between various tracked vehicles are relatively small.

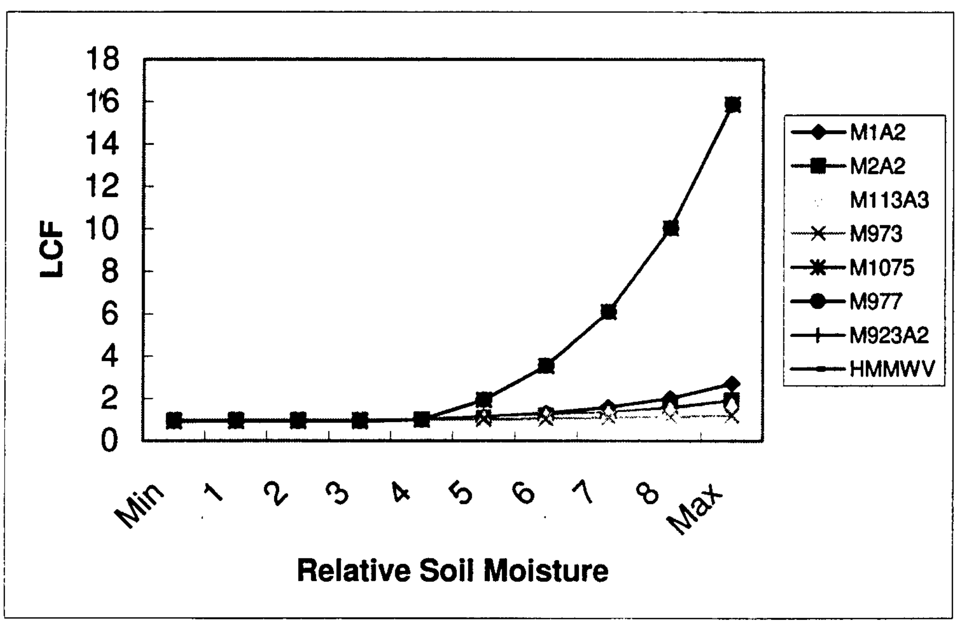

Figure 9. LCF for selected vehicles on a CL soil.

4 Applying VSF, LCF, and Models Within ATTACC

There are several options for integrating VSF/LCF methodology into the ATTACC program. First, a global set of VSF can simply be used in all existing ATTACC databases using a reference soil type. Second, site-specific VSF can be developed using a soil type specific to the installations. Third, VSF can be estimated for both wheeled and tracked reference vehicles. Finally, VSF equations can be incorporated into ATTACC software programs. Each approach has advantages and limitations. To facilitate using any of these approaches, an Environmental Systems Research Institute (ESRI) ArcView extension has been developed to automate VSF/LCF calculations.

The choice of implementation option will determine how much of the vehicle site interactions will be considered in the ATTACC methodology (Figure 10). Currently, ATTACC is accounting for only the type of vehicle and number of passes. Interactions between vehicles and site conditions are not being captured. Vehicle estimates can be improved by the proposed VSF methodology. Soil, moisture, and many other interactions can be accounted for by using the more rigorous VSF implementation options.

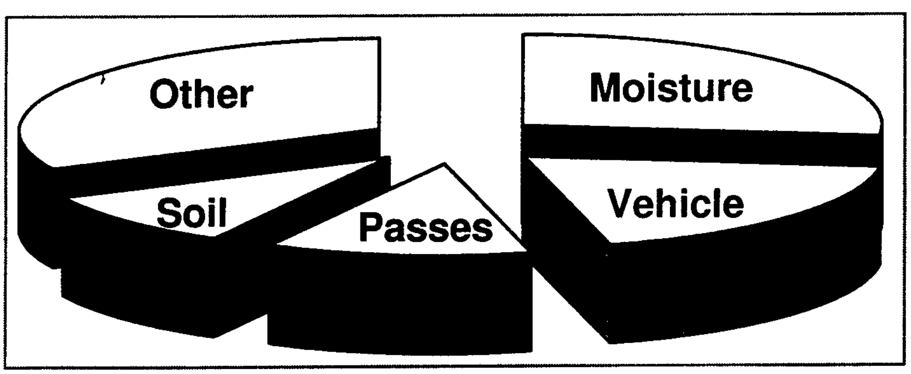

Figure 10. Proportion of variation in output accounted for by paramaters.

Global ATTACC VSF

Global VSF that are the same for all installations can be used in place of existing SME VSF for all installations. VSF would be based on the M1A2 standard vehicle that is represented by MIM. VSF would be developed for a reference soil type and moisture level. LCF would be based on the reference soil type and moisture level used in the VSF calculation. This approach has the advantage of being an objective approach for reproducible VSF/LCF based on current knowledge of vehicle impacts. Few implementation issues exist since the new VSF values simply replace the existing SME VSF within the ATTACC database. However, this approach does not account for many of the factors identified in this report as being important in predicting vehicle impacts. Differences in VSF resulting from different soil types and interactions between vehicle types and soil conditions would not be considered.

Table 13 provides global ATTACC VSF calculated using the methodology described in this report. A CL soil type was used since this represents a soil type commonly found in maneuver training areas. Representative soil moisture was calculated as described in Chapter 2. Vehicle data used to develop the proposed ATTACC VSF were obtained from NRMM databases and published values (Jane's 1999). Vehicle data used to calculate VSF are listed in the Appendix. The standard reference vehicle is a M1A2 as defined in the ATTACC methodology.

The values in Table 13 have the same limitation of the existing ATTACC SME VSF values. They are static values that apply to all sites and do not consider the interaction between vehicle properties, soil type, and soil moisture. However, these values are based on current knowledge of vehicle site impacts.

Figure 11 shows the relationship between ATTACC SME VSF and the proposed VSF. The relationship between the factors has a correlation coefficient of 0.88, meaning that the proposed VSF can explain approximately 77 percent of the variation in the ATTACC SME VSF values.

Table 13. Proposed ATTACC vehicle severity factors.

LIN	Vehicle Description	VSF
A93125	TANK: M551 (ARAAV)	0.6850
C10908	CARRIER: CARGO FAASV	0.8285
C11280	CARRIER: CARGO SUSV	0.6857
C12155	CARRIER: FISTV M981	0.5302
C18234	CARRIER: M113A3	0.5465
C76335	CFV: M3A1	0.7604
D11049	CARRIER: CARGO 6TON M548	0.5581
D12087	CARRIER: M113	0.5241

LIN	Vehicle Description	VSF
E56578	CEV: M728	0.8906
F40375	IFV: M2A2	0.7894
F60530	CFV: M3A2	0.7894
H57642	HOW SP 155,M109A6,PALADIN	0.8530
L43664	LAUNCH: M60	0.9047
L44894	MLRS LAUNCHER	0.8416
R50681	RECOVERY VEH: MED M88	0.9335
T07679	HMMWV: M1097	0.0464
T13168	TANK: M1A1 (MOD, 120 MM)	0.9788
T13169	TANK: M60A3 (105MM)	0.8886
T13305	TANK: M1A2 MAIN BATTLE	1.0000
T13374	TANK: M1 (105 MM)	0.9664
T40999	TRUCK: M1075 HVY PLS	0.1337
T59278	HEMTT: W/CRANE	0.1516
T59346	CUCV: M1008A1	0.0750
T61035	TRUCK TRACTOR: HET M911	0.5085
T61494	HMMWV	0.0318
W76473	TRAC FT HS ARMORED ACE:M9	0.5188
W88699	TRACTOR: BLDZ	0.5487
X39432	TRUCK: 5/4 TON M880	0.0648
X40009	TRUCK: 2.5 TON M35A2	0.0924
X40794	TRUCK: 5 TON 6X6 M923	0.1006
X40794	TRUCK: 5 TON 6X6 M923	0.1704
X40831	TRUCK: 5 TON M924/M925	0.1037
X40931	TRUCK: 5 TON M813A1	0.1595
X44403	TRUCK: 20 TON DUMP M917	0.5000
X60833	TRUCK: 1/4 TON M151	0.0229
Z40430	TRUCK: CARGO LMTV W/E	0.1147
Z40439	TRUCK: CARGO MTV W/E	0.1064

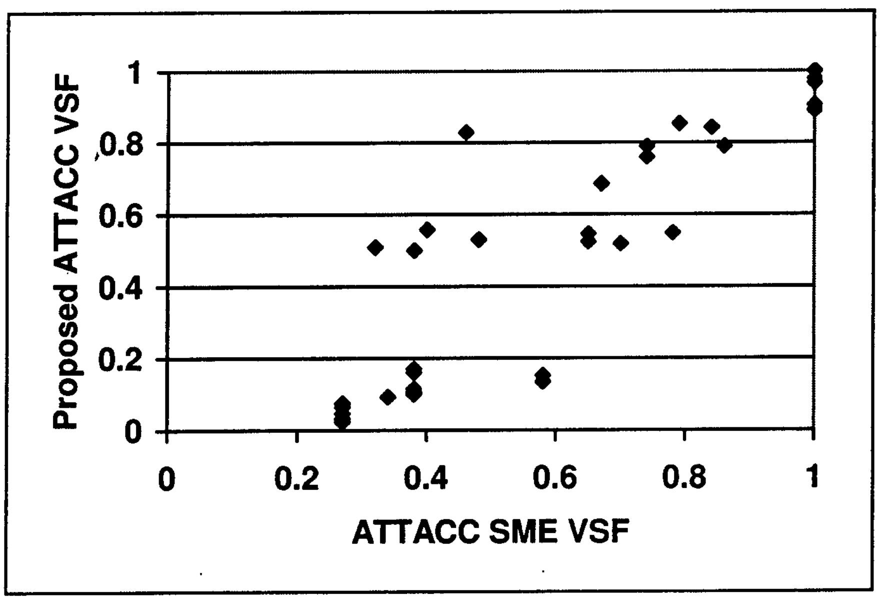

Figure 11. Relationship between ATTACC SME VSF and proposed VSF.

Local ATTACC VSF

VSF can be calculated for the dominant soil type of an installation or management area. VSF would be based on the M1A2 standard vehicle that is represented by MIM and would be developed for a reference soil moisture level typical of that soil type. LCF would be based on the selected soil type and moisture level used in the VSF calculation. This approach has the advantage of being an objective approach for reproducible VSF/LCF. Few implementation issues exist since the new VSF simply replace the existing SME VSF. However, different VSF would need to be fielded to each installation implementing the ATTACC program. While this approach considers differences in soil types, it does not consider vehicle by soil moisture interactions.

An ArcView extension has been developed to estimate ATTACC VSF and LCF using the equations in Chapter 2 and installation-specific soils data. This tool allows the user to specify a representative soil, soil moisture, and reference vehicle. Local ATTACC VSF and LCF are then calculated from vehicle data.

Separate Tracked and Wheeled MIM Calculations

VSF can be calculated for the dominant soil type of an installation with a different reference vehicle for tracked and wheeled vehicles. LCF would be developed for each reference vehicle (tracked and wheeled). This approach has the advantage of being an objective approach for reproducible VSF/LCF. All major aspects of vehicle, soil, and moisture interactions are considered. However, implementation would require changes in the existing ATTACC methodology. MIM calculations would need to be made for each vehicle type (wheeled and tracked) and maintained separately.

An ArcView extension has been developed to estimate ATTACC VSF/LCF using the equations in Chapter 2 and installation-specific soils data. This tool allows the user to specify a representative soil, soil moisture, tracked reference vehicle, and wheeled reference vehicle. Local ATTACC VSF and LCF are then calculated from vehicle data.

Incorporating Sinkage Equations into ATTACC

Sinkage equations can replace VSF and LCF in the ATTACC methodology. Vehicle impacts can be calculated directly from soil, weather, and vehicle data, which would fully capture most vehicle site interactions. However, implementation

would require changes in the existing ATTACC methodology and software systems.

Sinkage equations are documented in this report for inclusion in any ATTACC software system.

5 Conclusions

The methodology presented in this report for estimating ATTACC Vehicle Severity Factors and Local Condition Factors provides an objective, reproducible, scientific approach that meets the needs of the ATTACC program. The proposed methodology uses readily available existing data. Several implementation options are identified that would allow simple improvements to be made quickly with few implementation issues until more complete solutions are feasible.

The proposed VSF and LCF methodology is a consistent approach that ensures that environmental factors considered in one training impact factor are not considered again in other training impact factors. LCF and VSF have been defined and implemented in a consistent manner.

An ESRI ArcView extension is available to assist in developing VSF/LCF for each implementation option. This tool is also applicable for estimating VSF for new weapon systems as they are developed and fielded.

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Appendix: Vehicle Measurements and Weights

Table A1 provides vehicle parameters required for calculating vehicle severity factors. The list of vehicles was obtained from the ATTACC vehicle database. Vehicle parameters were obtained from the WES NRMM database.

Table A1. Vehicle parameters used to calculate ATTACC vehicle severity factors.

LIN	Vehicle Description	Type	Wt. (lb)	Clrnc (in.)	Wdth (in.)	Length (in.)	Dia. (in.)	Defl. (in.)	Sect. Ht. (in.)
T40999	M1075 PLS	W	8166	16.50	17.20		53	3.60	13.20
T59278	HEMTT:W/CRANE	W	7547	13.00	16.00		53	3.20	13.80
X40794	M923	W	5367	13.70	14.80		49	2.80	11.70
X40794	M923	W	5417	11.50	11.50		44	2.10	9.00
T61494	HMMWV	W	1875	11.30	12.30		37	1.90	9.20
T07679	HMMWV:M1097	W	2500	11.30	12.50		37	2.07	9.00
X60833	TRUCK: 1/4 TON M151	W	795	8.80	7.40		30	1.10	6.50
X40009	TRUCK: 2.5 TON M35A2	W	3038	12.50	11.00		42	1.60	10.40
X44403	TRUCK: 20 TON DUMP M917	W	9112	12.00	11.50		48	1.60	10.90
T59346	CUCV: M1008A1	W	2200	7.50	9.30		32	1.40	7.10
T61035	Truck Tractor: HET M911	W	12929	15.00	15.30		54	1.90	12.60
X39432	Truck: 5/4 Ton M880	W	2000	7.20	9.50		33	1.40	8.00
X40831	Truck: 5 Ton M924/M925	W	5467	13.70	14.80		49	2.80	11.70
X40931	Truck: 5 Ton M813A1	W	5205	11.50	11.50		44	2.10	9.00
Z40430	Truck: Cargo LMTV W/E	W	5685	13.75	15.30		46	2.49	11.10
Z40439	Truck: Cargo MTV W/E	W	5682	13.75	15.40		47	2.49	10.40
T13305	Tank: M1A2 Main Battle	T	70000	17.00	25.00	183.10			
C18234	Carrier: M113A3	T	13590	16.00	15.00	112.00			
F40375	IFV: M2A2	T	33000	17.50	21.00	157.00			
C11280	Carrier: Cargo SUSV	T	5290	14.00	24.00	156.00			
W88699	Tractor: BLDZ	T	24100	13.70	20.00	107.00			
D11049	Carrier: Cargo 6 ton M548	T	14200	16.00	15.00	114.00			
C12155	Carrier: FISTV M981	T	12900	16.00	15.00	109.00			
L44894	MLRS Launcher	T	28100	17.00	21.00	173.50			
A93125	Tank: M551 (ARAAV)	T	17500	17.50	17.50	142.80			
T13169	Tank: M60A3 (105MM)	T	58000	18.00	28.00	171.00			
W76473	TRAC FT HS Armored ACE: M9	T	17800	14.00	18.00	104.00			
L43664	Launch: M60	T	63500	14.00	28.00	171.00			
T13374	Tank: M1 (105MM)	T	60000	17.00	25.00	183.10			
T13168	Tank: M1A1 (MOD, 120MM)	T	63726	17.00	25.00	183.10			
D12087	Carrier: M113	T	11700	16.00	15.00	109.00			
R50681	Recovery Veh: MED M88	T	56000	17.00	28.00	183.00			
C76335	CFV: M3A1	T	25100	17.50	21.00	157.00			
E56578	CEV: M728	T	58700	18.00	28.00	171.00			
F60530	CFV: M3A2	T	33000	17.50	21.00	157.00			
H57642	HOW SP 155 M109A6 Paladin	T	33750	17.70	15.00	159.00			
C1098	CARRIER: Cargo FAASV	T	29300	17.70	15.00	159.00			

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13. ABSTRACT ***(Maximum 200 words)***

The Army Training and Testing Area Carrying Capacity (ATTACC) program is a methodology for estimating training and testing land carrying capacity. The methodology is used to determine land rehabilitation and maintenance costs associated with land-based training. ATTACC is part of the Army's Integrated Training Area Management (ITAM) Program.

The ATTACC methodology quantifies training load in terms of Maneuver Impact Miles (MIM), which are based on vehicle mileage projections. Each vehicle in each training event has a different impact on the land. To account for these differences, all training events are normalized to a standard unit in a standard event. The ATTACC standard is the M1A2 in an armor battalion in a field training exercise (FTX). Training impact factors represent the difference in impact between vehicles and events as compared to the standard. The factors used to calculate MIM are Vehicle Severity Factors (VSF), Event Severity Factors (ESF), Vehicle Conversion Factors (VCF), Vehicle Off-Road Factors (VOF), and Local Condition Factors (LCF).

Vehicle Severity Factors account for the differences in impacts due to different types of vehicles. Local Condition Factors account for differences in vehicle impacts due to weather variations. This report documents a methodology for estimating ATTACC vehicle severity factors and local condition factors. The methodology is based on a reanalysis of data and models used in the NATO Reference Mobility Model.

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